Diver-Portable Multi-Sensor Buried Mine-Hunter

Dr. Joseph L. Lopes, Code R21
Coastal Systems Station, Dahlgren Division
Naval Surface Warfare Center
6703 West Highway 98
Panama City, FL 32407-7001
Phone: (850)-235-5582 Fax: (850)-234-4886 E-mail: LopesJL@ncsc.navy.mil

Dr. Robert Marciniak
Applied Research Laboratory/Penn State University
P.O. Box 30
State College, PA 16804-0030
Phone: (814)-863-4839 Fax: (814)-865-3854 E-mail: rxm16@psu.edu

Mr. Donald L. Folds
Ultra-Acoustics, Inc.
4072 Hickory Fairway Drive
Woodstock, GA 30188
Phone: (770)-516-5031 Fax: (770)-516-6527 E-mail: dfolds2@bellsouth.net

Document #: N0001400WX20013

LONG-TERM GOALS

The goal of this task is to identify and develop acoustic sensor technology that can be diver-portable or integrated onto the front of an underwater vehicle. The sensor will be capable of detecting and localizing fully buried mines, and detecting, classifying, and localizing volume and partially buried mines. This task is a joint effort with the 6.3 Diver Core Program effort entitled, "Forward Looking Acoustic Sensors for Divers and Small Underwater Vehicles." The overall goal of this joint effort is to develop a complete system that will be no larger than 10-inches in diameter with a 20-inch length, will be neutrally buoyant in water, and will weigh less than 35 pounds in air.

OBJECTIVES

This task seeks to identify and develop technology that will detect and localize fully buried mines as well as to detect, classify, and localize volume and partially buried mines.

APPROACH

The approach to identify and develop the required technology for the buried mine sensor system that can be diver-portable or be attached to the front of an underwater vehicle consists of five distinct efforts. In the first effort, an assessment of individual sensor technologies was conducted to determine the most viable concept(s) for the sensor system. From this work, issues associated with candidate sensor concepts were identified and addressed in the second effort. In the third effort, the candidate sensor concept(s) will be designed, and algorithms needed to process and display the signals will be developed. The individual sensor(s) will be tested in the fourth effort. In the fifth effort, the sensor(s) will be integrated and demonstrated.

The key issues needed in identifying candidate sensor concepts include:

(a) Determination of the effectiveness of a sonar (frequency, aperture size, beam pattern, pulse type, signal processing techniques, etc.) to detect completely buried mines.

(b) Identification and development of the technology that will provide capability in classification.

(c) Integration and packaging of these sensors into a diver-portable unit or a unit that can be attached onto the front of an underwater vehicle.

In regard to issue (a), while there exists sonar performance models such as SEARAY and the shallow water acoustic tool set (SWAT) which predict sonar performance against volume and partially buried mines, there does not exist validated models that accurately predict sonar performance against buried mines. The key modeling issues are to accurately predict the amount of acoustic energy that can propagate into and out of the sediment. Several experiments have measured higher acoustic penetration into sediment at shallow grazing angles than expected.[1-4] Two proposed explanation for this penetration are: (1) the excitation of a biot slow wave in the sediment in which porosity and permeability of the sediment are important factors[5] and (2) scattering of the acoustic beam into the sediment by patches of roughness at the water-sediment interface.[6] In order to properly determine sonar tradeoffs (i.e., frequency, aperture size, beam pattern, etc.), an accurate accounting of penetration to, and backscatter from, a buried target needs to be incorporated into a sonar performance model. Thus, a validated model that predicts sonar performance against buried targets is unresolved.

WORK COMPLETED

In FY 1996, a concept feasibility study for an appropriate sensor concept was conducted. Results of this sensor technology assessment identified that a wide field-of-view (FOV), multiple-beam, dual-frequency (lower frequency for buried mine detection and higher frequency for imaging/classification capability) acoustic lens sonar was the best candidate sensor concept for a system that could be diver-portable or attached to the front of an underwater vehicle.[7] This study also identified important acoustic issues which included: (1) the lack of data associated with the material property (attenuation at frequencies less than 100 kHz and speed of sound) in candidate acoustic lens materials, and (2) the mechanism for bottom penetration at shallow grazing angles has not been resolved.

In FY 1997, two efforts were initiated to resolve these acoustic issues. In the first effort, an experiment was conducted to obtained measurements of attenuation and speed of sound for different candidate elastomeric materials (various compositions of neoprene, EPDM, and nitrile as well as hypalon and silicone). Results of this effort were used to determine a candidate lens design for the dual frequency system. In the second effort, a laboratory experiment was performed to test if the roughness diffraction mechanism permits an increase in penetration at shallow grazing angles. In this experiment, two immiscible fluids (vegetable oil floating on glycerin) formed layers separated by an interface where small polystyrene beads were floated to simulate roughness. An array of hydrophones placed in the bottom layer was used to measure the acoustic levels transmitted across the interface. Results of these measurements have demonstrated the following four points. First, a significant amount of acoustic energy is scattered into the bottom layer by the beads floating at the interface. Therefore, a non-flat sand bottom may cause an increase in transmitted acoustic energy at shallow grazing angles. Second, results from using the array as a beamformer have indicated that the scattered signals yield an apparent sound speed that is slower than that of a fast compressional wave; and thus, when beamformed, the scattered signals maybe mistaken as being due to a slow wave. Third, if roughness diffraction is the dominant mechanism for subcritical penetration, near field effects may be an issue; here, the scatterers at the interface act as the radiating source for signals transmitted into the bottom layer. Fourth, directionality of the interface scatterers will impact subcritical penetration. This second effort provided better understanding of effects of surface roughness on subcritical penetration.

In FY 1998, a partially populated, lower frequency portion of the candidate lens systems was designed and fabricated. The acoustic performance of this design was assessed against buried targets in a measurement conducted in the Very Shallow Water (VSW) region near the Army Corps of Engineers Field Research Facility in Duck, NC. The measurement employed three lower frequency subsystems identical in design, but with different diameters (apertures diameters of 20, 25, and 30 cm); these systems were attached to a stationary sonar tower complete with horizontal pan and vertical tilt motors. Calibrated retro-reflectors were used for buried targets, and a buried hydrophone array was employed to determine coherence of the transmitted signal in the sediment. Results indicated that an adequate signal-to-background ratio was maintained for target detection for each of the three diameter subsystems; signal-to-background increased with increasing diameter.[8] In addition, the coherence of the transmitted pulse was found to decrease with depth in the sediment and with increasing frequency.[8]

In FY 1999, a sonar aperture size of 25 cm was selected, and the dual frequency lens system was designed in a modular form. This aperture size was selected based on the combination of size constraints and the results of the FY 1998 testing. The system was designed such that the aperture of the lower frequency subsystem is truncated and the higher frequency subsystem is located at this truncated position. Fabrication of partially populated lower and higher frequency subsystems was initiated. A model, which models a target as a collection of cylinders, spheres, ellipsoids, and disks with each target component represented by an appropriate equation, was developed to create computer-generated images that would provide guidance in determining the sonar parameters required for classification-type images.[9]

In FY 2000, the partially populated lower and higher frequency lens subsystems were tested. The imaging capability of the higher frequency subsystem was assessed at the CSS Acoustic Test Facility against calibrated free-field targets. The lower frequency subsystem was assessed against targets buried at steep and at shallow grazing angles during the ONR sponsored Department Research Initiative (DRI) experiment "High-Frequency Sound Interaction in Ocean Sediments." This experiment was conducted in 60-ft water depth in the Gulf of Mexico near Destin FL. Both subsystems were further assessed against buried (lower frequency subsystem) and proud (higher frequency subsystem) targets during a measurement conducted at a sandy bottom site in St. Andrews Bay near the CSS Ammo Pier. This last set of measurements is presently in progress.

From the FY 2000 measurements, the sonar parameters for buried target detection will be finalized and the appropriate sonar parameters needed to obtain classification-type images will be determined. A fully populated dual frequency system will be fabricated and tested under the 6.3 Diver Core Program.

RESULTS

Results of the DRI experiment demonstrated detection of buried calibrated retro-reflectors at steep and subcritical grazing angles of 35^{o} and 20^{o}, respectively. Calibrated targets buried at a grazing angle 10^{o}

were not detected. Figures 1 and 2 are photos of the water-sediment interface taken over the steep (target #4) and shallow (target #5) buried targets, respectively. Figure 3 illustrates an image sector scan acquired with a 40 kHz, 0.1 ms sinusoidal pulse. The data shown in these figures were acquired under calm conditions and within 10 hours of a dive in which divers recorded that the retro-reflectors were buried by at least 6 mm of sediment. Backscattered returns from targets #4 [coordinates (5.3, 0)] and #5 [coordinates (8.4, 0)] are easily seen; the signal-to-noise ratio (SNR) is over 15 dB for target #4 and about 4 dB for target #5. This image sector scan corresponds to data obtained with a back up sonar system because a loose connection in the lower frequency lens subsystem's leak-tight canister prevented it from transmitting consistently during the experiment. This provided the motivation for conducting the assessment test near the CSS Ammo Pier, which is presently in progress.

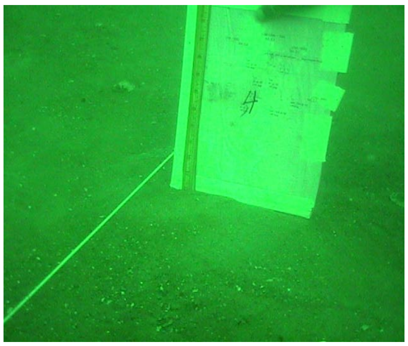

Figure 1. Water-sediment interface over buried target #4.

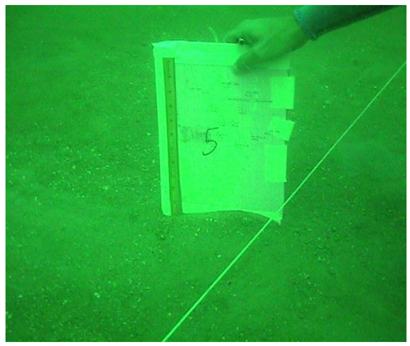

Figure 2. Water-sediment interface over buried target #5.

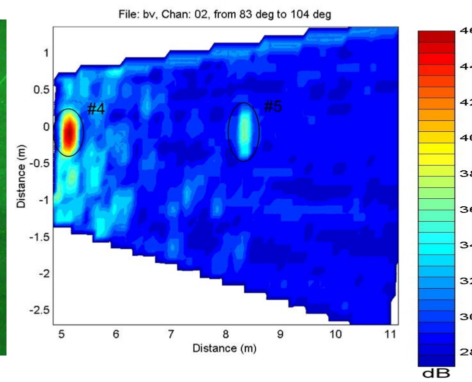

Figure 3. Image sector scan.

The higher frequency lens subsystem was also evaluated. At a frequency of 1.2 MHz, the two-way 3-dB down horizontal beam width was measured to be 0.27^{o}. Internal reflection levels within lenses were measured to be more than 35 dB down from incident levels. The imaging capability of this subsystem was also assessed against free-field targets. Figure 4 is a photo of one of the free-field targets. This target is a group of 6 vertical aluminum rods that are supported by a base-plate covered with sound absorbing rubber. Each rod has a diameter of 1.3 cm and is 30.5 cm high. The rods have center-to-center spacings of 1.9, 3.2, 5.1, 6.4, and 7.6 cm. Figures 5 and 6 are measured and computer-generated images of the target located 5.25 m from the sonar, respectively. In both figures, the four rods with the largest separation are resolved and the image of the two rods with the smallest spacing merge. In the measured image, some returns are apparent from the sound absorbing rubber covering the support plate, and a bright spot in the lower left of the image is an uncovered corner of the base plate. Clearly, the prediction of the imaging model compared well with measurement. This effort has also demonstrated that the higher frequency subsystem has a cross range resolution of 2.5 cm at ranges approaching 5.25 m.

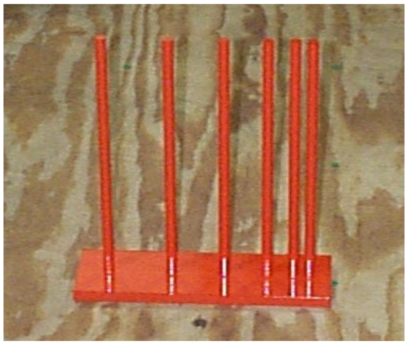

Figure 4. Photo of rod target.

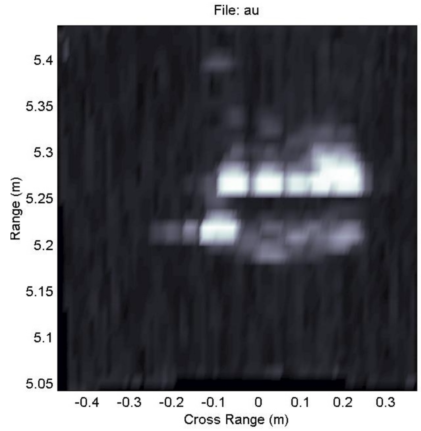

Figure 5. Measured image.

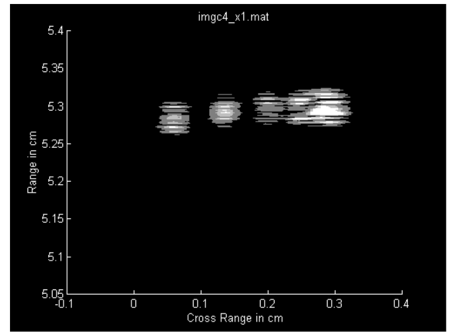

Figure 6. Computer -generated image.

IMPACT/APPLICATIONS

The diver-portable/forward looking sensor technologies developed under this task will be used to replace the Fleet AN/PQS-2A diver-portable sonar and to operate on small autonomous underwater vehicles (AUVs). The expected payoffs for the developed technology include:

- More reliable buried target detection capability than that of present systems
- Improved classification capability
- Higher area coverage rates
- Reduced mission execution times
- Higher probability of mission success because of fewer missed detection opportunities.

TRANSITIONS

The most likely transition path for the diver-portable multi-sensor buried mine-hunter and test results as well as any developed detection, and classifier technology will be to the Program Management Office - Explosive Ordnance Disposal (PMS-EOD) associated with the VSW Mine Countermeasures (MCM) Detachment or Special Operations Command (SOCOM). Another possible transition path for the developed classifier technology is PMS407 which sponsors efforts associated with the Fleet's Mine Neutralization System (MNS).

RELATED PROJECTS

This task leverages the work being conducted under the 6.3 Diver Program effort entitled, "Forward Looking Acoustic Sensors for Divers and Small Underwater Vehicles." to develop a complete dual frequency acoustic lens system.

The Direct Research Initiative (DRI) program “High-Frequency Sound Interaction in Ocean Sediments” is an ONR funded research effort that has an objective to provide a physical understanding of the observed penetration into sediment at shallow grazing angles.

An advanced motion compensation for Synthetic Aperture Sonar (SAS) task funded by ONR seeks to increase the area coverage rate of present SAS systems by developing sophisticated motion compensation algorithms.

An acoustic lens effort, funded by ONR under an EOD program, is using acoustic lens techniques to develop a high resolution, short-range (less than 10 meters) imaging sonar which will operate in the frequency range of 2 to 3 MHz.

REFERENCES

1. N.P. Chotiros, 1989. High Frequency Acoustic Bottom Penetration: Theory and Experiment, *IEEE Oceans'89 Conf. Proc.*, pp. 1158-1161.

2. J.L. Lopes, Observations of Anomalous Acoustic Penetration into Sediment at Shallow Grazing Angles, *J. Acoust. Soc. Am.*, **99**, 2473-2474 (Abstract).

3. H.J. Simpson and B.H. Houston, 2000. A Synthetic Array Measurement of Acoustical Waves Propagating into a Water-Saturated Sandy Bottom for a Smoothed and a Roughened Interface, *J. Acoust. Soc. Am.*, **107**, 2329-2336.

4. A. Maguer, E. Bovio, W.L. Fox, E. Pouliquen, and H. Schmidt, 1998. Mechanism for Subcritical Penetration into a Sandy Bottom: Experiment and Modeling Results, SR 287, SACLANT Undersea Research Centre, La Spezia, Italy.

5. N.P. Chotiros, 1995. Biot Model of Sound Propagation in Water-Saturated Sand, *J. Acoust. Soc. Am.*, **97**, 199-214.

6. E.I. Thorsos, D.R. Jackson, and K.L. Williams, 2000. Modeling of Subcritical Penetration into Sediments due to Interface Roughness, *J. Acoust. Soc. Am.,* **107**, 263-277.

7. J.L. Lopes, and I.A. Harris, 1997. Sensor Technologies Assessment for a Diver-Portable Buried Mine-Hunter System, CSS/TR-97/11, Coastal Systems Station, Dahlgren Division, Naval Surface Warfare Center, Panama City, FL, May.

8. J.L. Lopes, I.C. Paustian, R. Marciniak, and D.L. Folds, 1999. Dual-Frequency Acoustic Lens Sonar System Developments for the Detection of Both Buried Objects and Objects Proud of the Bottom, *Proceeding of SPIE AeroSense99*, Vol. 3711, 21-32.

9. J.L. Lopes, I.C. Paustian, R. Marciniak, D. Van Tol, and D.L. Folds, 2000. Imaging Capability of the Higher Frequency Subsystem of a Dual Frequency Acoustic Lens Sonar System, *Proceeding of SPIE AeroSense00*, Orlando, FL, April.

PUBLICATIONS

Lim, R., I.C. Paustian, and J.L. Lopes, Acoustic Transmission Across a Roughened Fluid-Fluid Interface, Submitted to the *Journal of the Acoustical Society of America*.

E.I. Thorsos, K.L. Williams, N.P. Chotiros, J.T. Christoff, K.W. Commander, C.F. Greenlaw, D.V. Holliday, D.R. Jackson, J.L. Lopes, D.E. McGehee, M.D. Richardson, J.Piper, and D. Tang, An Overview of SAX99: Acoustics Measurements, Submitted to the *Journal of Ocean Engineering*.

D.J. Van Tol and W.J. Hughes, 2000. Broadband Acoustic Transducer Used in Acoustic Beamformer, *Proc. of the Fifth European Conf. on Underwater Acoustics, ECUA 2000*, Lyon, France, July.

J.L. Lopes, I.C. Paustian, R. Marciniak, D. Van Tol, and D.L. Folds, 2000. Imaging Capability of the Higher Frequency Subsystem of a Dual Frequency Acoustic Lens Sonar System, *Proceeding of SPIE AeroSense00*, Orlando, FL, April.

D.J. Van Tol, 1999. Low Frequency Acoustic Lens 99 Final Report, Technical Memorandum 99-114, Applied Research Laboratory Penn State University, State College, PA, October.

J.L. Lopes, I.C. Paustian, R. Marciniak, and D.L. Folds, 1999. Dual-Frequency Acoustic Lens Sonar System Developments for the Detection of Both Buried Objects and Objects Proud of the Bottom, *Proceeding of SPIE AeroSense99*, Vol. 3711, 21-32.